

Examining Urban Brownfields through the Public Health “Macroscopic”

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Efforts to cope with the legacy of our industrial cities—blight, poverty, environmental degradation, ailing communities—have galvanized action across the public and private sectors to move vacant industrial land, also referred to as brownfields, to productive use; to curb sprawling development outside urban areas; and to reinvigorate urban communities. Such efforts, however, may be proceeding without thorough investigations into the environmental health and safety risks associated with industrial brownfields properties and the needs of affected neighborhoods. We describe an approach to characterize vacant and underused industrial and commercial properties in Southeast Baltimore and the health and well being of communities living near these properties. The screening algorithm developed to score and rank properties in Southeast Baltimore ($n = 182$) showed that these sites are not benign. The historical data revealed a range of hazardous operations, including metal smelting, oil refining, warehousing, and transportation, as well as paints, plastics, and metals manufacturing. The data also identified hazardous substances linked to these properties, including heavy metals, solvents, polycyclic aromatic hydrocarbons, plasticizers, and insecticides, all of which are suspected or recognized toxicants and many of which are persistent in the environment. The health analysis revealed disparities across Southeast Baltimore communities, including excess deaths from respiratory illness (lung cancer, chronic obstructive pulmonary disease, influenza, and pneumonia), total cancers, and a “leading cause of death” index and a spatial and statistical relationship between environmentally degraded brownfields areas and at-risk communities. Brownfields redevelopment is a key component of our national efforts to address environmental justice and health disparities across urban communities and is critical to urban revitalization. Incorporating public health into brownfields-related cleanup and land-use decisions will increase the odds for successful neighborhood redevelopment and long-term public health benefits. **Key words:** brownfields, cumulative risk, health disparities, urban health, waste management. *Environ Health Perspect* 110(suppl 2):183–193 (2002).

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Since the mid-1970s, legislative and policy boundaries have been drawn around the management of hazardous waste and the protection of the public health and the environment from the adverse effects of hazardous waste contamination. While myriad sites have been enrolled in federal and state hazardous waste management programs and subsequently tracked, evaluated, and, in many instances, remediated, hundreds of thousands of waste sites remain that are outside the reach of existing programs yet may pose significant public health and environmental risks.

Over the past decade, interest has been renewed in putting to use vacant industrial land, also referred to as brownfields, which the U.S. Environmental Protection Agency (U.S. EPA) defines as “abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination” (1). Through new and amended environmental legislation and policies, government agencies are developing long-term strategies to link the cleanup of vacant land to redevelopment. These efforts aim to reduce liability for potential purchasers and lending institutions and to increase flexibility in the cleanup and reuse of vacant or underused properties. The U.S. Department

of Housing and Urban Development estimated that over 90% of states have established some aspect of a voluntary cleanup program to ease the redevelopment of brownfields sites (2). The new administration also has singled out brownfields cleanup and redevelopment as a top environmental priority (3). Finally, on 11 January 2002, President Bush signed the Small Business Liability Relief and Brownfields Revitalization Act into law that aims to facilitate cleanup activities and redevelopment (4).

The potential benefits of reusing urban land, redirecting development away from pristine areas and increasing opportunities for neighborhood revitalization and economic expansion in distressed neighborhoods, are widely recognized. However, questions and concerns remain about whether new policies will protect the communities most affected by such measures and whether local health officials, regulators, and communities are prepared for the potential short- and long-term hazards of brownfields given the paucity of environmental data on these properties and the exposure risks that may ensue if we do not implement adequate technology-based and institutional controls and sustain them over time. Technology-based controls are pollution control requirements for point

sources (municipal wastewater treatment plants and industrial discharges) and non-point sources of pollution that are required by federal, state, or local environmental laws. The U.S. EPA defines “institutional controls” as they relate to hazardous waste sites as “legal mechanisms designed to control exposures to chemicals in environmental media, including soil and groundwater” (5).

The cleanup and redevelopment of vacant industrial land are issues that will affect poor, working-class, and minority communities, for better or worse (6,7). At first glance, the prospects of cleanup and concomitant redevelopment may be tantalizing given the promised economic benefits. At second glance, however, expedited cleanup and redevelopment may come at the community’s expense—environmental, social, economic, and public health harm—given the environmental unknowns of brownfields and the sensitive populations living in affected areas (7).

This study provides a starting point for investigators to examine brownfields through a public health lens—that is, to examine the potential hazards of brownfields both at a site-specific and at neighborhood levels and to identify opportunities for prevention and short- and long-term public health planning. Specifically, in this article we evaluate brownfields in Southeast Baltimore by tracing the historic operations of 182 vacant industrial sites. We screened sites for their hazard potential, drawing on hazard identification information, chemical persistence data, and physical characteristics of sites.

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Statistical models characterize the health of communities living near hazardous brown-fields areas.

Methods

Study Area Profile

Census data. We used data at the census-tract level for this research project. Census-tract boundaries, as defined by the U.S. Census Bureau, represent approximately 4,000 persons. Baltimore has 203 census tracts, 28 of which define the Southeast Baltimore study area. In terms of equity analyses, researchers have shown that the geographic extent of a study area (e.g., county, ZIP code, census tract, census block group, census block) may influence findings about the communities of concern, particularly as it relates to the location of the impact area that may be the basis for an inequitable situation (8,9). For this project, we chose the census tract as a starting point for characterizing brownfields communities. While these lines are political in nature, they provide basic information about the social and economic characteristics of Southeast Baltimore and were consistent with the impact area of interest—industrial brownfields properties and the geographic scale necessary to protect confidentiality of individual health information and preempt problems introduced by small numbers of cases and consequently unstable death rates.

For this research, we created and evaluated indicators using the 1990 census data to provide this broader context from which the “brownfields” issue can be considered and evaluated. These indicators included age, poverty status, population density, percent minority, percent working class, percentage of adults with less than a high school degree, percent vacant homes, percentage of families with income greater than \$50,000, and percent owner-occupied homes. The indicators aimed to capture community assets and economic strengths. For example, evaluating income levels at the neighborhood level may miss important insights about “family assets” that influence residential mobility and con-

sequently neighborhood stability. In this instance, we considered home ownership a reasonable proxy for wealth and included it in this analysis (10–14).

Health data. We obtained data on the leading causes of mortality for the population 45 years of age and older in Baltimore City for 1990–1996. These end points included heart disease, cancer, stroke, chronic obstructive pulmonary disease (COPD), diabetes, influenza and pneumonia, and liver disease. We selected these end points to capture the diseases that bear the greatest public health impact on Baltimore's communities for populations 45 years of age and older and that have been identified in the literature as being plausibly determined or influenced by environmental exposures (15–18). We developed age-adjusted mortality rates and mapped them at the U.S. census tract scale using ArcView, a geographic information system (19). We used the 1940 standard population for direct adjustment to facilitate comparisons with state and national data. Because the denominator consists of population 45 years of age and older, we readjusted the 1940 population standard weights accordingly. We calculated population estimates for intercensal years 1991 through 1996 by linear interpolation between the 1990 and 1997 U.S. census figures (20).

Building the Brownfields Scoring Algorithm

The methodology to rank brownfields involved a stepwise approach. It encompassed the development of scores specific to substance, site, and census tract, which the following four subsections discuss.

Step 1: site inventory. The Baltimore City Planning Department's inventory of vacant and underused parcels was the starting point for developing a brownfields-scoring algorithm. Site-specific address information, parcel size, current occupancy, land value, and several other parameters were available for each site. To trace past uses of these sites and construct a comprehensive

profile of the study properties, we consulted the following resources: Baltimore City Real Estate Tax Assessments (1935–1997); the Baltimore City Health Department archives; the Maryland Department of Environment Divisions of Waste Management, Air and Radiation, Water Management, and Technical and Regulatory Services, and Baltimore Manufacturing Directories, among other resources. Details about these data sources and the data collected are described elsewhere (21).

Step 2: substance score. From the review of facility files and other reference materials, we developed a chemical substance database. This database included chemicals used in past processes or released on site, as recorded in facility files or other industrial records. We then populated the database with information on the hazard potential and chemical persistence. This screening algorithm is limited by available testing data and thus provides a first step in understanding the range of hazards associated with urban brownfields.

For each chemical, we assigned hazard scores and chemical persistence weights and combined them to derive scores for each substance:

$$\text{Substance score}_n = \text{hazard score}_n \times \text{chemical persistence weight}_n \quad [1]$$

We derived this type of weighting algorithm, in part, from the U.S. EPA Hazard Ranking System (22), which the Superfund program uses to characterize hazards at hazardous waste sites, and the U.S. EPA Toxics Release Inventory Relative Risk-Based Environmental Indicator Initiative (22,23). It also draws on Tran et al.'s (24) application of a proportional weighting scheme to evaluate the acute and chronic health risks for military personnel deployed overseas.

The following subsections discuss the individual components of Equation 1. Table 1 summarizes these components, their chemical characteristics, the assigned weights, and the data sources.

Hazard score. Hazard scoring methods using quantitative metrics such as the LC₅₀,

Table 1. Description of hazard potential-persistence algorithm components.

Parameter	Description	Weight assignments	Source
Chemical persistence	K_{oc} : The measure of a chemical's tendency "to sorb to soil or sediment organic matter" (30).	$K_{oc} > 10,000 = 1,000$ $1,000 < K_{oc} < 10,000 = 100$ $100 > K_{oc} = 10$	(44) (45)
Hazard potential	<i>Recognized toxicant</i> : An agent that has been studied by national or international authoritative and scientific regulatory hazard identification efforts. Information on recognized toxicants was available for three broad categories of health effects: cancer, reproductive, and developmental. <i>Suspected toxicant</i> : Agents that have been shown to have target organ toxicity in either humans or two mammalian species by a relevant route of exposure. Information on suspected toxicants related to the following broad categories of health effects: cardiovascular/blood, developmental, endocrine, gastrointestinal/liver, immunologic, kidney, musculoskeletal, neurologic, reproductive, respiratory, skin/sense organs, and cancer.	Recognized toxicant = 10 Suspected toxicant = 5	(25–27)

LD₅₀, reference dose, or cancer slope factor have been used for risk ranking and screening purposes (22,23). We considered these approaches, but LC₅₀ and LD₅₀ were not applicable for chronic effects, and reference dose and cancer slope factor were not available for a majority of chemicals present at the brownfields sites included in the study. To capture the full range of substances of concern in the study, we developed a semiquantitative approach using the qualitative “weight of evidence” information on thousands of chemicals included in the Environmental Defense’s Scorecard Initiative (25) and the quantitative weighting schemes.

For each substance in the scorecard database, the “weight of evidence” for 12 broad categories of health is captured as a “recognized” and/or “suspected” toxicant. A recognized toxicant refers to agents that have been studied by national or international authoritative and scientific regulatory hazard identification efforts (26). Suspected toxicants are agents that have been shown to have target organ toxicity in either humans or two mammalian species by a relevant route of exposure (27). Together, these data provided a means to use toxicologic information for screening purposes and maximize information on a wide range of chemical substances.

To quantify the scorecard’s weight of evidence, we assigned a “suspected” effect a weight of 5 and a “recognized” health effect a weight of 10. The aim of this weighting system was to emphasize the proportional differences between recognized and suspected toxicants. We considered ordinal ranking schemes for this analysis, but they were limited in illustrating the relative differences in hazard potential between substances. Table 1 defines recognized and suspected toxicants and describes the weights assigned to these substances.

Multiple recognized or suspected health effects are associated with each substance in the brownfields chemical database. Thus, by summing the weights associated with the effects, a hazard score for each substance can be derived. These scores will be limited by the availability and extent of toxicity data. Lead provides an example of a substance that is associated with more than one health effect and is classified as both a recognized and a suspected toxicant. Based on the scientific literature, it is recognized as a carcinogen as well as a reproductive and developmental toxicant and is suspected to be toxic to the respiratory, neurologic, gastrointestinal/liver, skin and sense organ, cardiovascular and blood organ, kidney, immunologic, and endocrine systems. Based on the weight of evidence, we derived the following hazard score for lead as follows:

$$\text{Hazard score for lead} = (3 \text{ recognized effects} \times 10) + (8 \text{ suspected effects} \times 5) = 70 \quad [1a]$$

Chemical persistence. Soil contamination from past industrial uses is one of the major exposure pathways for local residents, remediation crews, construction workers, and current occupants of brownfields properties. Therefore, we selected a metric of chemical persistence (K_{oc}) as a proxy for substance’s fate in the environment. A chemical with high adsorptive capacity is less likely to volatilize into the air. The K_{oc} has been adopted by the U.S. EPA in its soil screening guidance (28) and applied to the Superfund chemical data matrix (29).

We assigned proportional weights to the K_{oc} value associated with each substance (30), which are described in Table 1. Substances with a K_{oc} greater than 10,000 are recognized to adsorb to soil organic carbon. Substances within the middle range may or may not adsorb, depending on other physical-chemical characteristics associated with the substance and the soil. Finally, substances with a low K_{oc} will not adsorb to organic carbon (30,31).

Metals such as chromium, lead, nickel, iron compounds, copper compounds, and aluminum are recognized to be highly persistent compounds that do not degrade in the environment (32). Therefore, we applied a weight of 1,000 to each of these compounds to capture their persistence in the environment.

Step 3: site-specific score. For each brownfields site, we calculated a total score representing all substances (n) found at each site (Equation 2a). Once we developed a site score, we weighted it by other site-specific information such as duration of operation for each property by use and parcel size (Equation 2b). Where this information was missing, we assigned the average duration of operation (i.e., 46 years). We applied the weight as a multiplier to each site score.

$$\text{Site score A} = \sum_n (\text{substance score})_n \quad [2a]$$

$$\text{Site score B} = \text{site score A} \times \text{years of operation} \times \text{acreage} \quad [2b]$$

Step 4: tract-specific score and rank. We calculated a score for each tract by aggregating the site-specific scores (j) in each census tract (Equation 3a). At the tract level, we applied a weight for adjusted density of sites (total sites per square mile minus acreage of parkland and waterways) as a multiplier to derive tract-specific scores (Equation 3b).

$$\text{Tract score A} = \sum_j (\text{site score B})_j \quad [3a]$$

$$\text{Tract score B} = \text{tract score A} \times \text{site density} \quad [3b]$$

We ranked the tract-specific scores and grouped them into ranges using the SAS RANK procedure (33). The three groups or “zones” represented 16 tracts with a low hazard potential (zone 1), five tracts with a medium hazard potential (zone 2), and seven tracts with a high hazard potential (zone 3). These three zones formed the basis for a newly created categorical variable, referred to as a brownfields indicator, to be used in the statistical analysis as described in the following section.

Multivariate Statistical Modeling

We used log-linear models to evaluate health status across brownfields zones. The following sections describe the independent and dependent variables and the statistical models.

Independent variables. Brownfields indicator. The brownfields indicator was the independent variable of interest, which we created from the tract-specific score as discussed in the previous section. We classified the census tracts into zones 1–3 as described above.

Social class and demographic indicators. We evaluated the socioeconomic variables for correlation and narrowed to two principal components to simplify the regression model (34). The first two principal components accounted for 75% of the variance of the five variables. Upon examining the loadings, the first principal component (PC1) represented percent owner-occupied homes, poverty status, and minority populations and the second principal component (PC2) represented percent working class and educational attainment. We then included these factors in the log-linear regression model as the socioeconomic covariates.

Dependent variables. The leading causes of mortality were the dependent variables. We obtained these data from the Baltimore City Health Department for years 1990 through 1996. We also restricted the data to deaths for the population 45 years of age and older. The end points included leading cause of death index, cancer (all-cause, lung, colon, bladder, stomach, oral, head and neck, skin), heart disease, COPD, diabetes, cerebrovascular disease, influenza and pneumonia, and liver disease.

Log-linear model. The base statistical model included the brownfields indicator (categorical) and population age (categorical). An extended model considered the contributions of population age, socioeconomic factors (PC1 and PC2), and area of census tracts:

$$\text{Log(expected deaths)} = \beta_0 + \beta_1(\text{brownfields indicator}) + \beta_2(\text{population age}) + \beta_3(\text{area of census tract}) + \beta_4(\text{PC1}) + \beta_5(\text{PC2}) \quad [4]$$

We used SAS GENMOD to estimate regression coefficients, with age-specific population estimates as the offset term. The model assumed a log link and a Poisson distribution. We used chi-square tests and resid-

ual plots to evaluate the fit of the models and calculated the odds ratios as measures of association by exponentiating the β coefficient. We present the results of each model as odds ratios with 95% confidence intervals (.35).

Results

Study Area Profile

Figure 1 displays the brownfields inventory for Baltimore City and provides a delineation

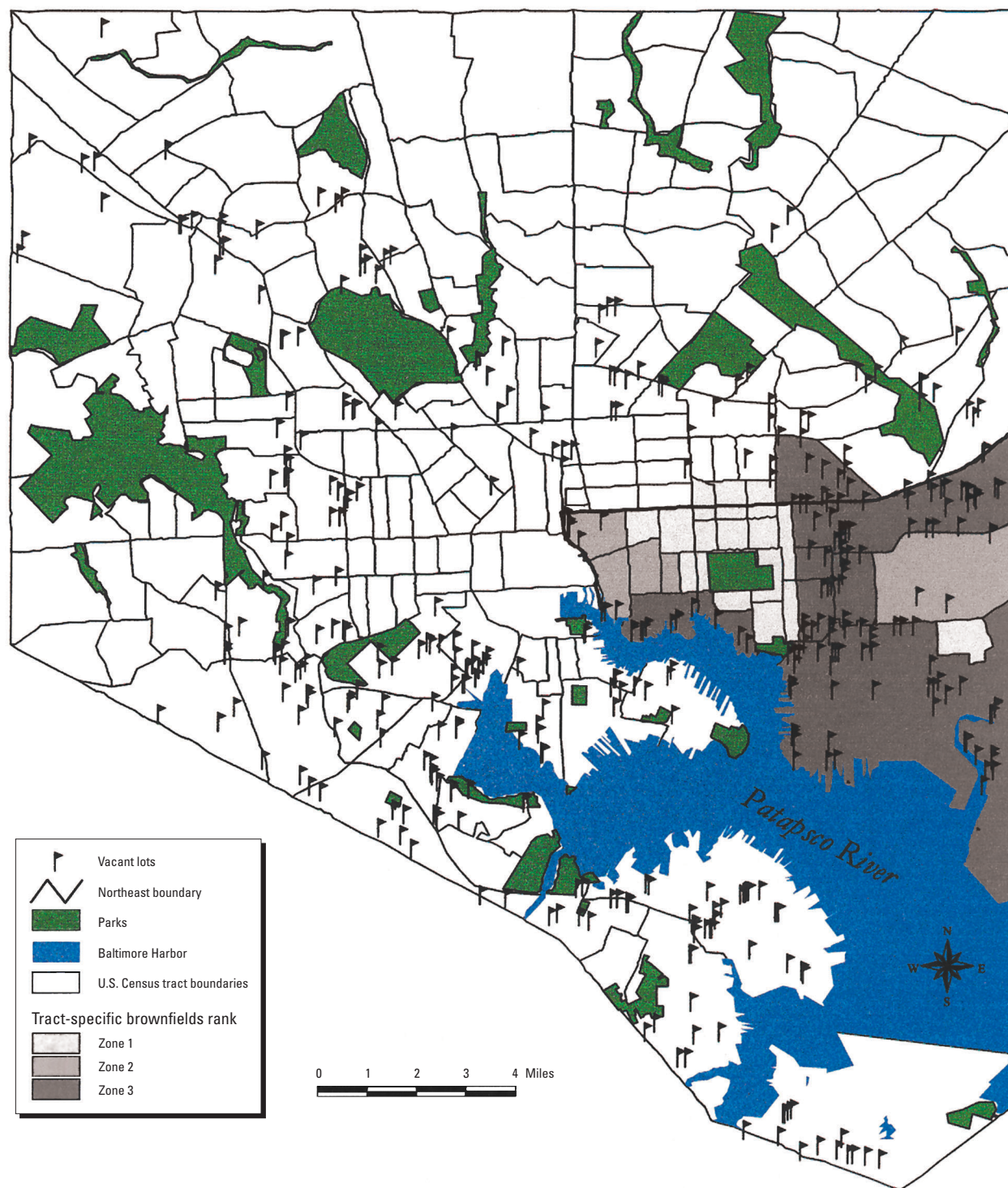


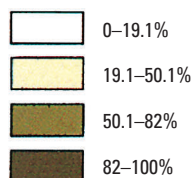
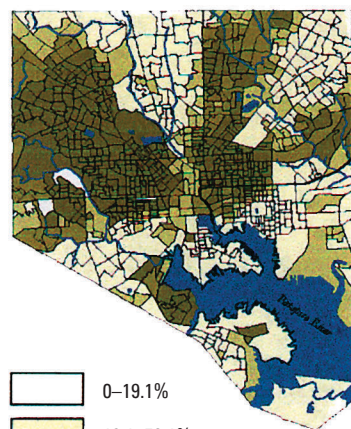
Figure 1. Map of vacant lots in Baltimore City. This figure displays 480 vacant and underused industrial and commercial properties in Baltimore that are ≥ 1 acre in size. We identified these sites by the Baltimore City Planning Department in 1997 through a grant from the U.S. EPA brownfields pilot program. Within Southeast Baltimore, 182 sites are ≥ 1 acre. The shaded areas reflect brownfields zones, as designated from the brownfields hazard-persistence algorithm. The darkest gray areas reflect census tracts with highest brownfields score.

of the study area and the spatial extent of the three brownfields zones within the study area based on the results of the brownfields algorithm. Table 2 provides average percentages for each socioeconomic indicator for Baltimore City (excluding Southeast Baltimore) and Southeast Baltimore, averages by brownfields zones in Southeast Baltimore, and the spatial display of these indicators are in Figure 2A–F. Figure 3A and B compares age-adjusted mortality rates in Southeast

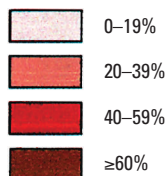
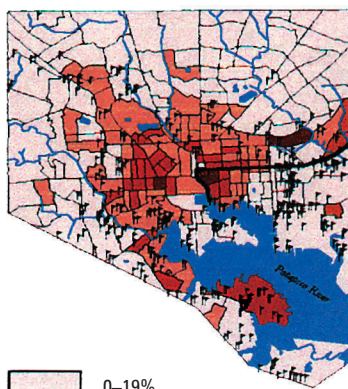
Table 2. Summary of socioeconomic indicators in Baltimore (percent).

Variable	Rest of city	Southeast	Southeast (brownfields zone)		
			Zone 1	Zone 2	Zone 3
Minority population	62	32	37	62	5
Poverty status	22	26	27	50	15
Less than high school degree	28	45	44	38	53
Owner-occupied homes	48	51	52	25	59
Family income \$50 K or higher	21	16	15	14	20
Working class	70	73	75	71	69

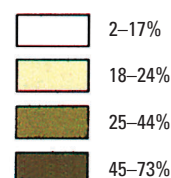
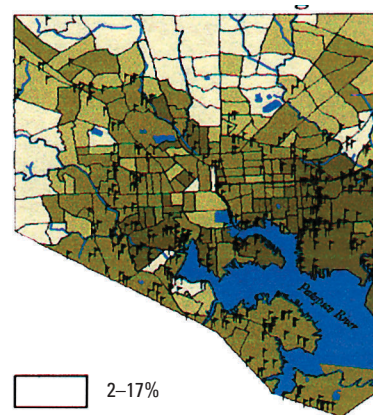
A Percent minority



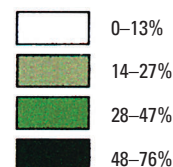
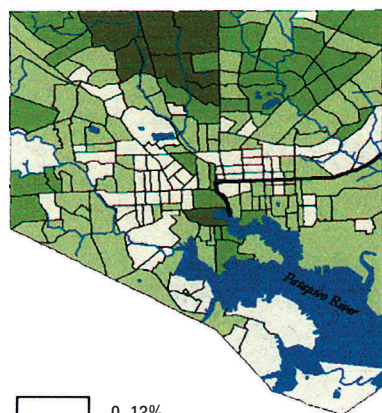
B Poverty status



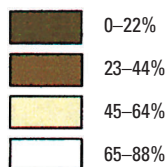
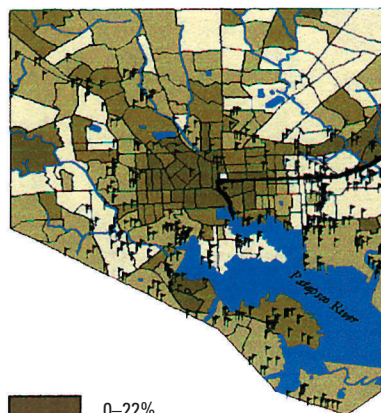
C Less than HS degree



D Family income ≥\$50,000



E Home-owner occupancy



F Working class

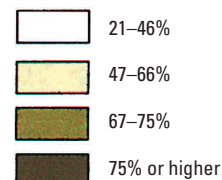
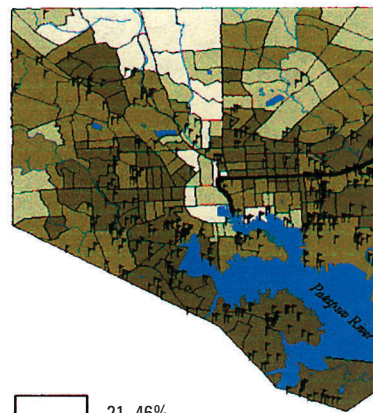


Figure 2. Spatial display of socioeconomic trends in Baltimore City. (A) Percentage minority by census block group. (B) Percentage below poverty level by census tract. (C) Percentage with less than a high school (HS) degree. (D) Percentage of families earning greater than \$50,000. (E) Percentage home-owner occupancy. (F) Percentage working class, as defined by 8 of 13 census occupational groups: administrative support; sales; private household services; other services (except protective services); precision production, crafts, and repairs; machine operators, assemblers, and inspectors; transportation and material moving; handlers, equipment cleaners, and laborers.

Baltimore with rates for the rest of the city, for Maryland, and for the United States. The data illustrate that, for key causes of death, Baltimore (both Southeast Baltimore and the rest of the city) suffers from excess mortality for heart disease, total cancers (specifically cancers of the lung, colon, stomach, and bladder), COPD, diabetes, influenza and pneumonia, and liver disease. Figure 3C–H presents the spatial distribution of the age-adjusted rates by census tract across Baltimore City using a geographic information system (19). These data together paint a picture of baseline health status in Baltimore and provide a context from which to consider these trends by comparing them with those for Maryland and the United States.

Brownfields Ranking Results

Substance-specific score. For this analysis, we identified persistence data for 90 of the 122 substances (74%). “Weight-of-evidence” hazard information from the scorecard database was available for 105 substances included in the brownfields chemical inventory (85%). For example, of the 105 substances, 71 (68%) have indications of respiratory effects, and 69 substances (66%) have indications of neurologic effects. Table 3 lists the complete number of chemicals in this study’s database and the associated health categories.

On the basis of the hazard identification–chemical persistence score, lead, polychlorinated biphenyls (PCBs), nickel, chromium, copper compounds, iron compounds, phthalates, toluene diisocyanate (TDI), and naphthalene comprised the top 10 substances associated with brownfields sites. When ranking the substances on hazard information, the leading substances were lead, benzene, cadmium, PCBs, ethylene oxide, TDI, pentachlorophenol, toluene, acrylonitrile, and beryllium. When ranking the substances on chemical persistence information, the top 10 substances were lead, PCBs, nickel, chromium, iron compounds, copper compounds, butyl benzyl phthalate, dioctyl phthalate, TDI, naphthalene, and creosote.

Table 3. Number of chemicals in study database and associated toxicologic end points.

Toxicologic end point	Number of chemicals in study database
Respiratory toxicity	71
Neurologic toxicity	69
Gastrointestinal and liver toxicity	58
Skin or sense organ toxicity	58
Cardiovascular and blood toxicity	49
Renal toxicity	35
Cancer	25
Immunologic toxicity	19
Endocrine toxicity	14
Developmental toxicity	10
Reproductive toxicity	4
Musculoskeletal toxicity	3

These lists constitute the same actors, with a higher ranking of heavy metals when ranking on chemical persistence alone. Table 4 displays the top 10 substances based on their hazard–persistence rank and provides the range of health categories associated with each of the top ranking substances.

Site-specific score. For the study area analysis, we evaluated 173 of the 182 sites (95%) identified by the ranking methodology. Information on site acreage was available for all 182 sites. We determined duration of operation for 66% of the sites. The top 10 past uses included scrap metal recycling, bot-

tle cap manufacturing, chemical manufacturing (e.g., inorganic pigments, plastics, synthetic rubber, industrial organics, fertilizers, and pesticides), steel manufacturing, and warehousing. Figure 4 provides a spatial display of these properties relative to the other properties in the site inventory. Of the facilities examined in the study, over 20% were once regulated or are currently regulated under state or federal environmental regulatory programs, including hazardous and solid waste programs, air management, and clean water programs. We conducted sensitivity analyses to understand the contribu-

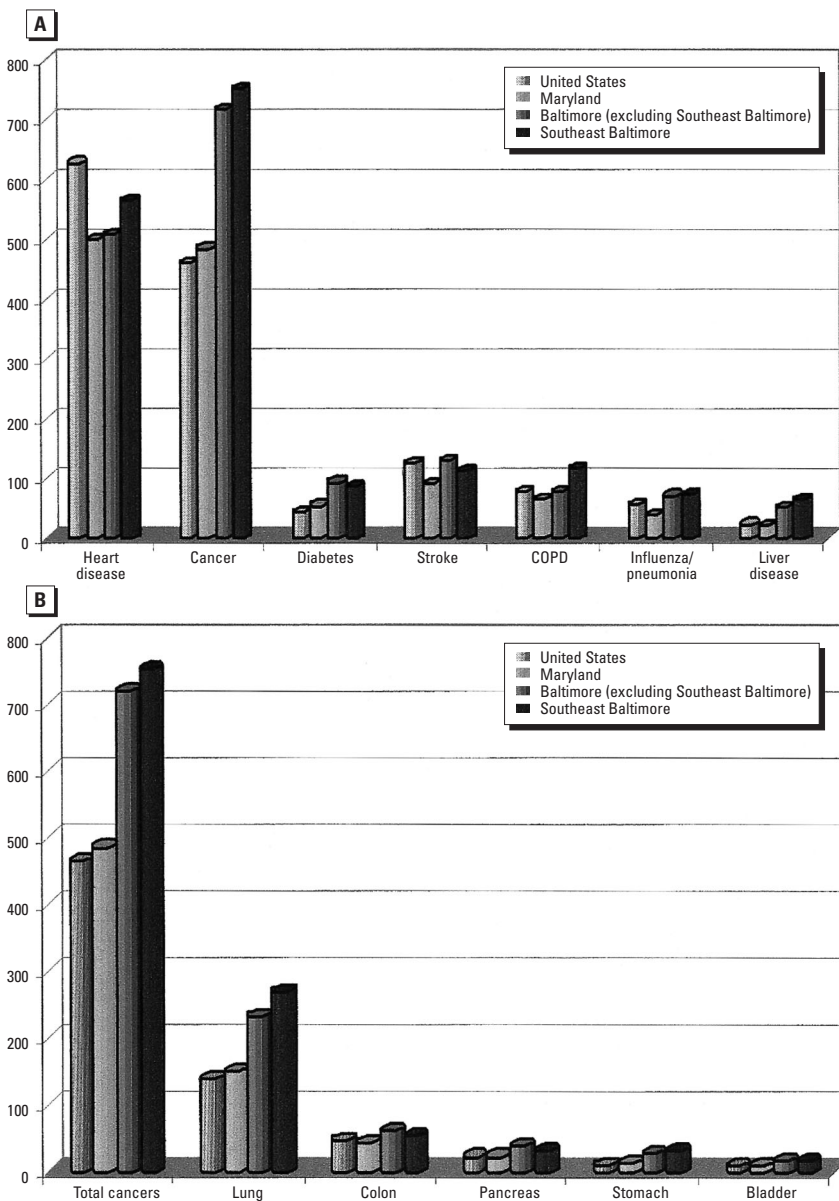


Figure 3. Age-adjusted mortality rates (per 100,000) for leading causes of death in Baltimore City’s population 45 years of age and older. (A, B) Age-adjusted rates for the leading causes of death and leading causes of cancer deaths, respectively, based on Baltimore City mortality trends for 1990 through 1996. These rates reflect the population 45 year of age and older. We age adjusted the rates to the 1940 standard population, recalculated the standard weights for the age adjustment, and compared the rates for Southeast Baltimore with the rest of Baltimore City and with the United States. We calculated all comparison rates based on the population 45 years of age and older (*continued*).

tions of each variable to the overall site-specific score. We provide a summary of such findings below and discuss the results from our final score.

The primary chemical substances driving the high-ranking properties included heavy

metals (lead, nickel, copper iron, and chromium), plasticizers (PCBs) used for metal castings, aromatic hydrocarbons (benzene, toluene, ethylbenzene, and naphthalene), iron compounds, and solvents (tetrachloroethylene). When ranking proper-

ties on their hazard potential, the list of top 10 facilities captured the city's paint and chemical manufacturers, which concentrated in Southeast Baltimore. When ranking the properties on chemical persistence alone, the top 10 facilities included a larger percentage of primary and secondary metals operations and waste disposal sites. When including other characteristics of the sites, such as duration of operation and parcel size, the list broadened in its coverage to include the petroleum refining industries and past railroad operations. These establishments occupy larger tracts of land and represent over 100 years of operations.

Tract-specific score. The tract scores reflected information on site-specific hazard potential and chemical persistence, total site acreage per tract, and total number of sites per tract. Figure 5 displays the tracts, based on the hazard-persistence scores. The two highest-ranking tracts contain approximately 66% of all the brownfields sites considered in the analysis. The past uses of these sites include petroleum refining, primary and secondary metals industries, paint manufacturing, and service industries such as dry cleaning establishments, gasoline service stations, and auto repair shops. The highest ranking tracts are located in the most industrial areas of Southeast Baltimore and are surrounded by Baltimore's active and currently regulated industrial operations.

Brownfields and Community Health

We developed four statistical models to examine the relationship between key variables and mortality in Southeast Baltimore. The base model included the brownfields indicator, population age, and area of census tract (after adjusting for parkland and water). We then expanded these models to adjust for socioeconomic factors that may be strong determinants of community health. Table 5 displays the results from the final fitted model, which included all significant covariates.

In Southeast Baltimore, communities living in the highest brownfields zone (zone 3), when compared with communities living in low brownfields zones (zone 1), experienced statistically higher mortality rates due to cancer (27% excess), lung cancer (33% excess), respiratory diseases (39% excess), and the major causes of death (index of liver, diabetes, stroke, COPD, heart disease, cancer, injury, and influenza and pneumonia; 20% excess). We observed these differences after adjusting for well-known risk factors such as population age and socioeconomic status. For end points such as diabetes, heart disease, and stroke, we observed no statistically significant differences across the brownfields zones. Additionally, although we observed declines in health between zone 3 and zone 2 and

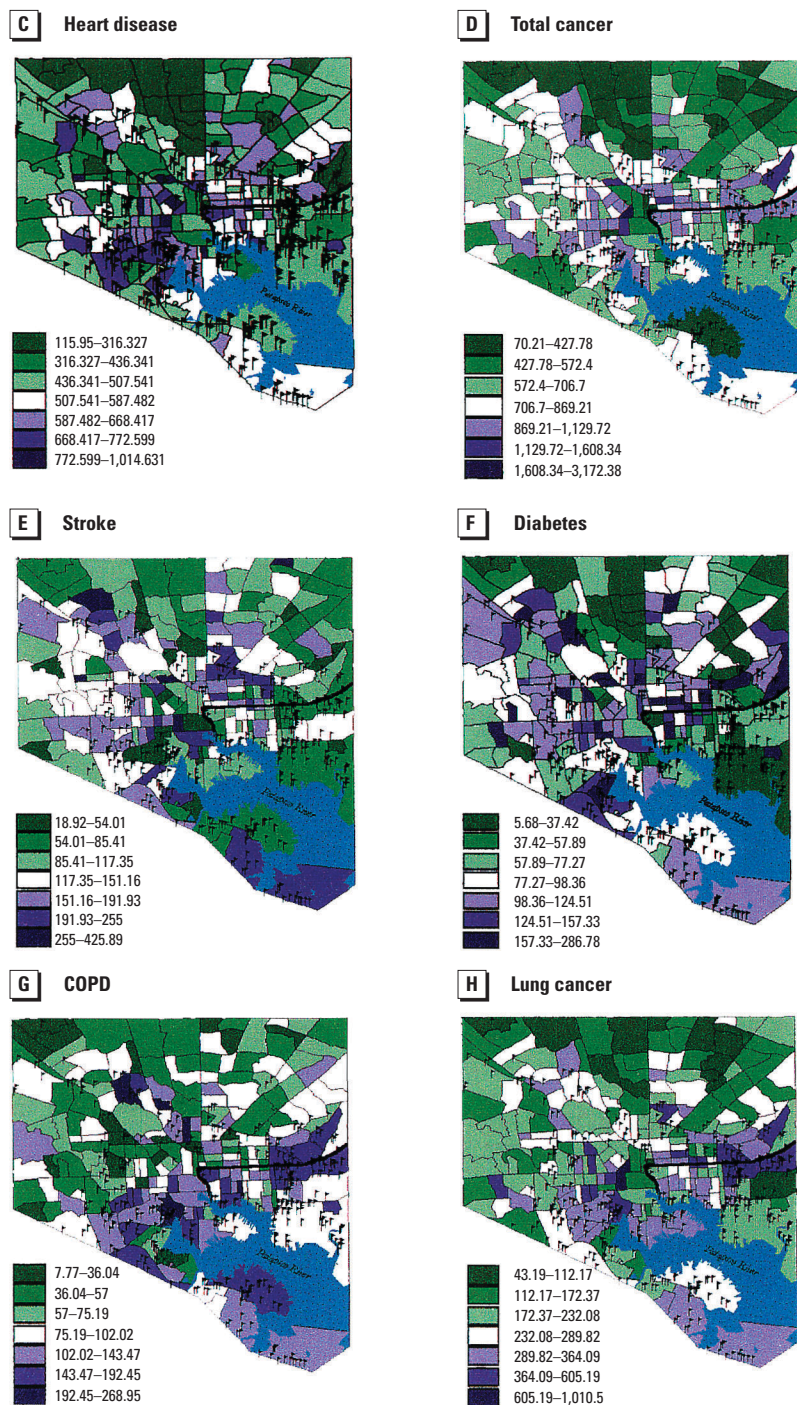


Figure 3 (continued). (C–H) present the spatial display of the age-adjusted rates for Baltimore City by census tract. We chose these end points to provide a snapshot of the variation in mortality patterns across the different leading causes of death for the population 45 years of age and older. We obtained the spatial data from the 1995 Topologically Integrated Geographic Encoding and Referencing System, a digital database available from the U.S. Census Bureau. We obtained the inventory of vacant and underused properties from the Baltimore City Planning Department in 1997. We used the tricolor ramp to emphasize rates below the city average (green) and rates exceeding the citywide average (purple). The tracts displayed in white reflect the average range of mortality for the city.

between zone 2 and zone 1, we observed no significant differences within these comparisons. The model used for this analysis was useful in capturing extreme differences between neighborhoods. However, further enhancements to the model and refined classification of sites may improve our under-

standing of more subtle differences among zones that were not detectable by the existing statistical model.

Discussion

Historical records, toxicologic information, and environmental fate data, in general,

illustrated that brownfields properties are not benign. Despite their dormant status, brownfields properties may pose potential chemical and physical risks to Baltimore's communities. Given the absence of population exposure data and site monitoring data, the methods developed for this analysis

Table 4. Rank of top 10 chemicals based on hazard and chemical persistence information.^a

Chemical substances	Hazard-chemical persistence rank	Respiratory toxicity	Neurologic toxicity	Gastro-intestinal/liver toxicity	Skin/sense organ toxicity	Cardio-vascular and blood toxicity	Renal toxicity	Cancer	Immuno-toxicity	Endocrine toxicity	Developmental toxicity	Reproductive toxicity	Musculo-skeletal toxicity
Lead	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Polychlorinated biphenyls	2	✓	✓	✓	✓			✓	✓	✓	✓		
Nickel	3	✓	✓		✓			✓	✓				
Chromium	4	✓		✓	✓								✓
Iron compounds	5	✓	✓	✓		✓	✓						
Copper compounds	6	✓	✓	✓		✓	✓						
Butyl benzyl phthalate	7		✓							✓			
Dioctyl phthalate (di- <i>n</i> -octyl)	8									✓			
TDI	9	✓	✓	✓	✓	✓	✓	✓	✓				
Naphthalene	10	✓	✓	✓	✓	✓	✓						

^aWe obtained data on toxicity end points from the Environmental Defense's Scorecard Initiative (25).

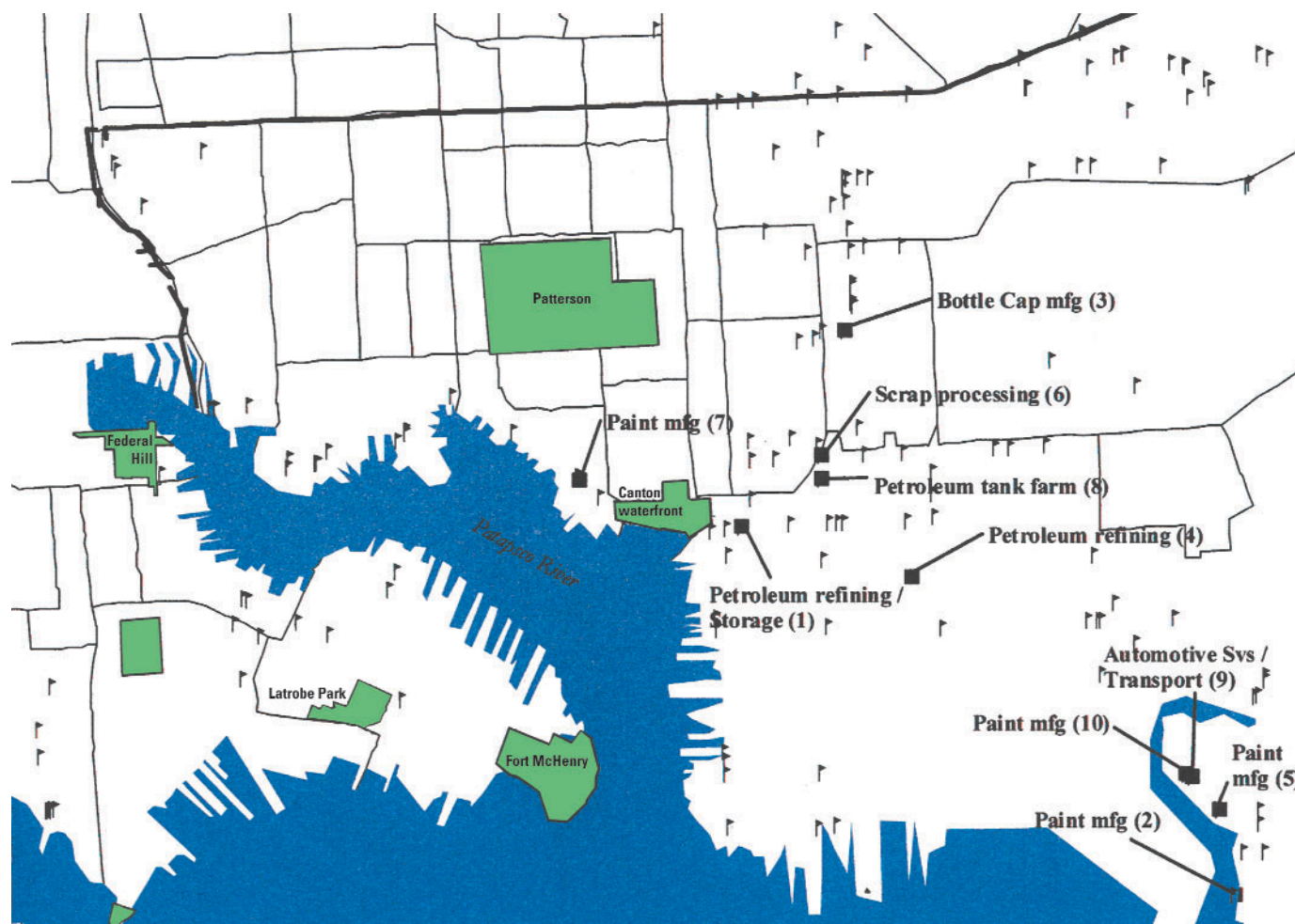


Figure 4. Spatial display of top 10 sites (numbered 1–10) based on hazard-persistence score. The sites displayed in this map of Southeast Baltimore represent a range of operations, from primary and secondary metals manufacturing and processing, to petroleum refining and storage, to paint manufacturing and transportation operations. We based these ranks on the algorithm that included information on hazard potential, persistence, and physical characteristics of properties. The sites are scattered throughout Southeast Baltimore and are located in close proximity to residential neighborhoods. We overlaid this map with the total inventory of vacant and underused industrial and commercial lots.

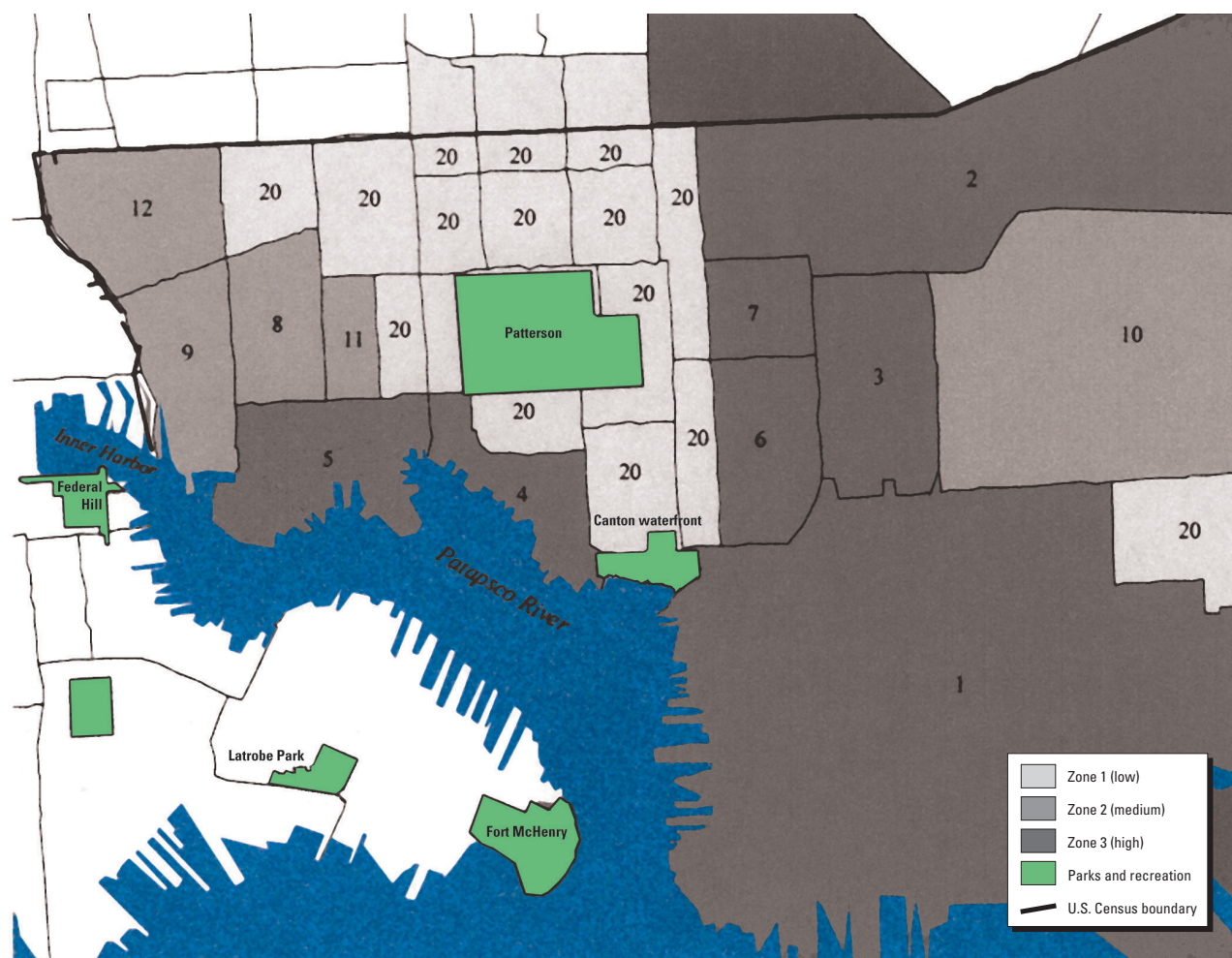


Figure 5. Spatial display of tract-specific brownfields rankings for Southeast Baltimore. This figure presents the final ranking of census tracts based on chemical and physical characteristics of the sites located within each census tract. The shades of gray reflect broader groupings of tracts based on degree of brownfields hazard potential, with the darkest shade reflecting areas of high brownfields hazard potential and lightest gray reflecting tracts with lowest brownfields hazard potential.

Table 5. Mortality and cancer morbidity trends in Southeast Baltimore across brownfields zones—final model.

Independent variables	Dependent variables											
	Top causes of death			Cancer			Lung cancer mortality			Respiratory mortality index (COPD, influenza, lung cancer)		
	OR	95% CI	Pr > Chi	OR	95% CI	Pr > Chi	OR	95% CI	Pr > Chi	OR	95% CI	Pr > Chi
Intercept	0.087	0.083, 0.091	0.0001	0.02	0.019, 0.022	0.0001	0.005	0.004, 0.006	0.0001	0.014	0.013, 0.016	0.0001
Brownfields												
Zone 3	1.20	1.10, 1.31	0.0001	1.27	1.09, 1.48	0.0023	1.33	1.03, 1.73	0.03	1.39	1.15, 1.68	0.0007
Zone 2	0.95	0.88, 1.03	0.27	0.98	0.84, 1.13	0.73	0.90	0.69, 1.17	0.44	1.00	0.84, 1.21	0.93
Zone 1	1.00			1.00			1.00			1.00		
Age group (years)												
45–54	0.11	0.10, 0.12	0.0001	0.15	0.12, 0.17	0.0001	0.27	0.20, 0.37	0.0001	0.10	0.08, 0.13	0.0001
55–64	0.25	0.23, 0.27	0.0001	0.40	0.35, 0.46	0.0001	0.63	0.50, 0.79	0.0001	0.31	0.26, 0.37	0.0001
65–74	0.40	0.37, 0.42	0.0001	0.59	0.52, 0.66	0.0001	0.89	0.72, 1.09	0.25	0.54	0.47, 0.63	0.0001
≥75	1.00			1.00			1.00			1.00		
Factor 1 ^a	1.10	1.06, 1.14	0.0001	1.09	1.02, 1.16	0.009	1.11	0.99, 1.24	0.07	1.11	1.02, 1.20	0.01
Factor 2 ^b	0.90	0.85, 0.95	0.0003	0.91	0.82, 1.01	0.08	0.96	0.80, 1.14	0.64	0.95	0.84, 1.09	0.51
Adjusted area of census tract	0.96	0.94, 0.99	0.009	0.96	0.91, 1.00	0.07	0.90	0.83, 0.98	0.02	0.92	0.86, 0.97	0.008
										0.90	0.81, 1.02	0.10

Abbreviations: OR, odds ratio; Pr > Chi, *p*-value for the chi-square statistic, which indicates that the parameter values other than the intercept are significant. ^aFactor 1: percent minority, percent poverty, percent owner-occupied homes. ^bFactor 2: percent working class, percent with less than high school degree.

demonstrate that it is possible to screen and rank brownfields properties based on their hazard potential and consider brownfields at both a site-specific and neighborhood-specific level. The socioeconomic indicators evaluated for this analysis highlighted the constellation of economic and class issues that define communities living in close proximity to historic brownfields hazards. The health information provided important insights about the vitality of and cumulative environmental risks facing affected communities and revealed disparities in health across brownfields zones.

Importantly, these data underscore the need for a coordinated public health and community-based planning approach to brownfields redevelopment. Opportunities for prevention and public health planning must begin with improved environmental health surveillance to track historic hazards in the environment, population exposures to chemical and physical hazards, and priority health conditions in the population. From an emergency response perspective, such tracking information will help uncover past industrial and commercial practices at hundreds of sites and thus aid frontline responders to prepare for events including fire, injury, or unintended population exposures that may occur at these sites. Furthermore, by identifying priority substances of concern, public health officials and environmental regulators, together with affected communities, can develop strategies for biomonitoring or area monitoring if they deem it necessary to better understand population exposures.

Finally, better environmental health tracking information can facilitate plans for future land use and the appropriateness of institutional controls to protect communities over the long term. Public health screening data, for example, can be used to set site cleanup standards and inform local environmental policies, particularly where cause-and-effect relationships between environmental exposures and health effects are difficult to establish yet where public health concerns are real and environmental pollution and degradation persist. Below we describe other examples that illustrate the utility of environmental health information.

In 1998, the Public Interest Law Center of Philadelphia developed an Environmental Justice Protocol to protect communities with substandard health from local sources of pollution, regardless of the cause of the substandard health, and to assure that permit reviews, future land use decision making, and community development are transparent and reflect the needs of affected communities. The center, in its proposed protocol, calls for the establishment of public health standards to guide permit reviews and other

local environmental decision making based on an assessment of age-adjusted all-cause mortality rates, age-adjusted cancer mortality rates, infant mortality rates, and low-birth-weight rates (36).

In Massachusetts, the legislature is currently considering language to establish an Environmental Justice Designation program. Similar to 1975 Massachusetts legislation that designates "areas of critical environmental concern," this legislative act would enable the Massachusetts Executive Office of Environmental Affairs to designate areas of environmental justice concern based partly on community health information (37). Finally, the Boston Public Health Commission has included language in its regulations on waste container lots to consider the cumulative impacts of environmental pollution on public health and safety when reviewing industrial and commercial permits (38). In Baltimore, such approaches would allow for the inclusion of community health concerns such as excess deaths from respiratory-related illness in the design and implementation of redevelopment strategies for aging industrial areas, thus reorienting environmental policies to be responsive to local issues and affected communities.

More broadly, the creation and persistence of brownfields in Baltimore underscore the need for a balanced policy approach that includes both people and place strategies—one that focuses on the rebuilding of social capital (e.g., neighborhood cohesion), human capital (e.g., professional skills), physical capital (e.g., infrastructure), and natural capital (e.g., natural resources and living systems) to improve community health and restore neighborhood vitality (39–41). Sviridoff (42) once noted, "[E]conomic incentives alone are unlikely to transform workers with few skills into productive assets, nor chaotic environments into profitable commercial or industrial sites." Fullilove and Fullilove (43) have opined that "the decline in [community] health is the inevitable outcome of the collapse of place." Rebuilding brownfields neighborhoods through an integrative public health and planning approach will be essential for improving the odds for sustainable redevelopment and securing long-term gains in public health.

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